ME MTech (Res) Thesis Colloquium

Steady Sedimentation of Particles in Long Vertical Tube and Effect of End Boundary Conditions on Convective Motion

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ABSTRACT

Sedimentation – settling of particles in a fluid- is observed in nature like rain droplets and dust particles in the atmosphere, and in a variety of industrial processes, like to clarify liquid as well as separate particles of different size and density. The simplest system is the sedimentation of mono-disperse particles in a vast stationary fluid. The main parameters are Particle Reynolds Number (Re_p based on terminal velocity), ratio of particle density to fluid density ($\frac{\rho_p}{\rho_f}$), particle volume fraction (φ), and container dimensions for experimental and numerical methods. Two main questions arise: what is the mean settling velocity (V_g), and nature and values of fluctuation in particle velocity ($V^/$), and how do they compare with the terminal velocity (V_t) of an isolated particle in an infinite fluid. At low particle Reynolds number, V_t is given by the Stokes law. Experiments have been typically performed in a tank containing the fluid with particles initially well mixed and tracking the motion of the particles or performing PIV to obtain mean settling velocity (V_g), fluctuating particle velocities ($V^/$) etc. The main focus of these studies has been to correlate different parameters like mean settling velocity, velocity fluctuation, correlation length with volume fraction, and dimension of the container. Though this apparently simple problem has been studied theoretically, experimentally, and numerically over many decades, there are several unanswered questions. For example, the experimental results for velocity fluctuations do not agree with the theoretical predictions. The origin of scalings for velocity fluctuations are unclear. In our study, we try to address some of these issues using a new type of experiment.

In our experiment, particles are fed at a constant rate at the top and allowed to settle in a long vertical tube containing quiescent fluid, closed at the bottom. The constant particle feed rate ensures mean steady particle settling in contrast to the standard experiments done previously where the settling process is transient. Also, the long vertical extent of the tube ensures Axial Homogeneity. We have done two types of experiments: water droplets (10-15 μm, $Re_p \sim 10^{-3}$) falling in the air, and spherical glass beads (100 μm, $Re_p \sim 1$) settling in water. The estimated volume fractions for the former is 10^{-7} and for the latter, it is 10^{-3}. For the droplet-air system, the tube dimension is $5 \times 5\ cm^2$ and for the particle-water system, three tube dimensions ($4 \times 4\ cm^2$, $5 \times 5\ cm^2$, $7 \times 7\ cm^2$) have been used. Experiments have been done with different mass flux values. We have used high-speed imaging illuminated by a sheet of laser light to visualize the particle motion fields and Particle Image Velocimetry (PIV) to get the mean and fluctuating particle velocities and the spatial and temporal correlations. We have observed a variety of sedimentation-induced convective motions, including regions of particle patches moving upwards. The conditions at the tube end significantly alter the convective patterns and the fluctuating velocities. Convective motions, though hypothesized to exist, have not been observed in earlier experiments. We present results for the mean and fluctuating velocities and spatial and temporal correlations of the velocity fields for the range of mass fluxes and different tube dimensions. Besides the existence of convective motion, the main findings are: the mean settling velocity varies between $0.80 - 1.1\ V_t$. The fluctuating velocities are in the range $0.30 - 0.80\ V_t$ and strongly depend on mass flux. Correlation lengths scale with tube width. We present these results in a non-dimensional form which suggest different scaling laws.

ABOUT THE SPEAKER

Deepan Sharma completed his Bachelor's from Motilal Nehru National Institute of Technology, Allahabad. He joined IISc in 2018 and worked with Prof. Jaywant Arakeri in Experimental Fluid Mechanics Lab, Department of Mechanical Engineering. His primary research focus is understanding fundamentals of multiphase flows.